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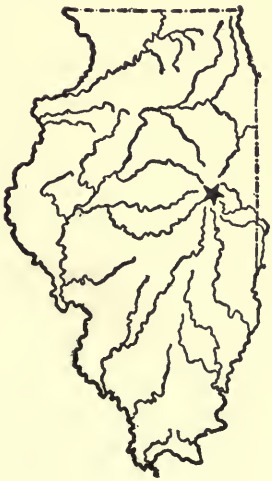
BULLETIN No. 264

WHEAT ROSETTE AND ITS CONTROL

IN COOPERATION WITH OFFICE OF CEREAL INVESTIGATIONS
BUREAU OF PLANT INDUSTRY, U. S. DEPARTMENT OF AGRICULTURE

By H. H. McKinney, R. W. Webb,
and G. H. Dungan



URBANA, ILLINOIS, APRIL, 1925

SUMMARY

Rosette is a disease of unknown cause occurring on a few varieties of winter wheat. Altho in many ways it behaves as a definite disease restricted to these varieties, there are indications that it may constitute only a very severe phase of what appears to be a mosaic disease occurring on a rather large number of winter wheats.

Rosette was first observed in 1919 near Granite City, Madison county, Illinois. Later it was found in Sangamon, Mason, and Logan counties, Illinois, and in LaPorte, Porter, and Tippecanoe counties, Indiana. When the disease was first observed it was thought to be the take-all disease, but later studies show that it is distinct from take-all.

Altho rosette has caused great loss in infested fields, it has never been of general economic importance because it is controlled by the use of resistant varieties. The disease appears in the early spring, producing spots in the infested fields where it causes the plants to become dwarfed. Many of the older leaves of infected plants turn a blue-green color, whereas the younger growing leaves develop a typical mosaic mottling at some time in their development.

No fungus is consistently associated with the vital tissues of diseased plants in the early spring. *Helminthosporium sativum* and other fungi occur superficially on a few of the plants and later in the spring a secondary rot sets in.

Microscopic examinations show the presence of necrotic areas, or lesions, in the interior of the tissues of the crown region of diseased plants and a characteristic inclusion body is also present in many of the cells. These cell inclusions are also associated with plants of varieties which are affected with a mosaic mottling of the leaves, but which never develop the rosette symptoms. Cell inclusions have never been found in the plants of any variety growing in soil known to be free from the leaf mottling causal agent.

These cell inclusions are similar to certain of those associated with the known virus disease of other plants, and they also are similar to some which are found in association with certain of the virus diseases of man and the lower animals. Their exact nature is not known.

The cause of rosette has been attributed by some workers to *Helminthosporium sativum*; however, the experimental evidence presented in this paper does not favor this conclusion. At the present time there are indications that it may be caused by some unusual type of virus. The rosette and leaf mottling conditions are soil-borne. Rosette and mosaic leaf mottling developed in great abundance in air-dried infested field soil which had been stored under greenhouse conditions for three years.

The disease is controlled experimentally by treating infested soil with an .8-percent solution of formaldehyde and by disinfecting the soil with steam. It is completely controlled in the field by the use of resistant or immune varieties; those best adapted to the infested areas include: Blackhull, Fulcaster, Fultz, Gipsy, Gladden, Kanred, Mammoth Red, Michikoff, Red May, Red Rock, Red Russian, Red Wave, and Turkey. The list of most susceptible varieties includes: "Brunswick," Fultz (Kentucky selection), Harvest Queen (white chaffed Red Cross), Illini Chief, Missouri Bluestem, Nigger, and Penquite. Many of the varieties which are resistant to rosette are highly susceptible to the mosaic leaf mottling. In but few cases, however, does this condition seem to be of economic importance.

WHEAT ROSETTE AND ITS CONTROL

By H. H. McKinney, R. W. Webb, and G. H. Dungan[a]

The rosette disease of wheat was reported from Madison county, Illinois, in April, 1919. Later, it was found in other counties in the state and in several counties in Indiana. At that time the disease was thought to be the take-all disease which occurs in Australia and in Europe. However, investigations which have been reported[6] show that the rosette disease differs from take-all in plant symptoms and also in its varietal and host ranges. Furthermore, *Ophiobolus graminis,* the fungus which causes take-all, has never been found associated with the rosette disease.

Altho in many ways rosette behaves as a definite disease restricted to a limited number of varieties of winter wheat, this interpretation should not be definitely accepted at this time. It was pointed out in a previous publication[10] that there is a considerable amount of evidence which indicates that the rosette disease may constitute a severe expression of a mosaic disease.

Soon after the discovery of the rosette disease, cooperative investigations of the malady were started by the Office of Cereal Investigations, United States Department of Agriculture, and the Illinois, Indiana, and Wisconsin Agricultural Experiment Stations. It is the purpose of the present bulletin to summarize the principal results of these investigations.

OCCURRENCE OF ROSETTE

The rosette disease has been found in four counties in Illinois and in three counties in Indiana, as shown in Table 1. It is very likely that the infested area is greater than that shown in the table, but as most wheat varieties commonly grown are not susceptible to rosette, additional areas cannot readily be detected.

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The writers wish to express their appreciation to Dr. W. L. Burlison and Dr. A. G. Johnson for helpful criticisms during the preparation of the manuscript; to Dr. C. E. Leighty, who supplied most of the seed used and furnished information in regard to characteristics and adaptation of wheat varieties; to Mr. J. B. Kendrick for cooperation in the control experiments; to the Board of Education of Granite City, Illinois, for providing laboratory facilities; and to Mr. Louis Soechtig, on whose land the experiments were conducted.

TABLE 1.—DISTRIBUTION OF THE ROSETTE DISEASE IN THE UNITED STATES

State	County	Number of infested fields found	Approximate acreage of infested fields
Illinois	Madison	27	670
	Mason	48	1310
	Sangamon	2	380
	Logan	1	20
Indiana	LaPorte	7	213
	Porter	6	120
	Tippecanoe	1	5

The distribution of the mosaic mottling independent of rosette has not been determined. Rosette is not known to occur in other countries and consequently nothing is known of the origin of the malady. When

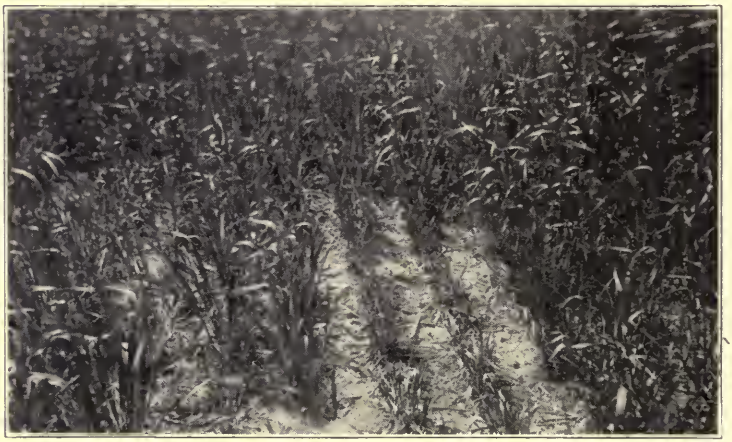

FIG. 1.—SPOT IN A FIELD OF HARVEST QUEEN (SALZER'S PRIZETAKER, RED CROSS) CAUSED BY THE ROSETTE DISEASE

The diseased plants within the spot are considerably dwarfed in contrast with surrounding healthy ones.

more information has been obtained on the cause of the disease and its relation to the mosaic leaf mottling, more light may be thrown on its distribution and origin.

LOSSES CAUSED BY ROSETTE

Altho the rosette disease appears to be confined to relatively small areas, its importance should not be underestimated. When conditions are favorable the disease has caused as high as 40 percent actual loss

of grain in a 50-acre field. It is not uncommon to find many spots or large areas in a field where practically all the wheat plants have been killed or are severely diseased. Sometimes, however, the diseased plants in such spots recover to a considerable extent and produce some grain, altho the heads are much smaller than those produced by rosette-free plants (Fig. 2). In this case, however, ripening is delayed and the plants are green when the normal crop is harvested. The grain from such green plants shrivels badly and much of it is lost in threshing. When much of a field is affected by the disease and there has been considerable recovery, the greatest quantity of grain is saved by delaying harvest until the diseased areas are ripe. In some cases, it is best to harvest the healthy and diseased areas separately, thus reducing losses to the minimum.

CROPS AFFECTED

Investigations carried on thus far have not shown any other crop than winter wheat to be affected by the rosette disease. Various crops have been tested for susceptibility to the disease[6] and only a limited number of winter wheat varieties have been found susceptible.

DESCRIPTION OF WHEAT ROSETTE

During the first year's investigations, it was not possible to make a complete study of the symptomatology of the disease owing to the fact that the studies were not started until the trouble had reached a rather advanced stage. At that time, field spotting was conspicuous, and diseased plants showed a characteristic stunted development and the production of an excessively large number of secondary tillers, which gave the plants a rosette appearance. These were the field and plant symptoms which attracted attention to the disease and which made it conspicuously different from other wheat diseases heretofore known in this country. A rotting of the underground portions of tillers was evident at that time, but this condition was considered a secondary effect rather than a primary cause.

In 1920 and each year since that time, the field studies have been started just at the time when winter wheat plants were beginning to show signs of spring development and before the underground portions of the plants commenced to rot.

FIELD SYMPTOMS

Shortly after the wheat plants start their spring growth, infested fields will develop very striking areas or spots where the diseased plants do not develop normally (Fig. 1). These spots vary in size and shape. In some cases, one diseased plant may be found among plants showing no signs of disease. It is not uncommon to find spots 20 feet in diameter and even larger. In some cases, more than 95 percent of the area of a field

may show infestation. The spotting caused by the disease occurs independently of topographical variations, and frequently single patches are found which involve a poorly drained dead furrow and adjacent well drained portions of land. Usually, the diseased plants partially recover by sending up secondary tillers which do not ripen until after the healthy plants are mature, thus causing a green spotting in the infested fields during the ripening period.

Field spotting is caused by several wheat diseases and therefore it is not specific for the rosette disease. Most of the foot rot diseases pro-

FIG. 2.—THREE POORLY DEVELOPED HEADS FROM PLANTS OF HARVEST QUEEN PARTIALLY RECOVERED FROM THE ROSETTE DISEASE AND THREE TYPICAL HEALTHY HEADS AT RIGHT

duce this condition, but in most cases these can be distinguished from rosette by means of the plant symptoms. The field spotting produced by the take-all disease caused by *Ophiobolus graminis* Sacc. does not develop as early in the spring as the spotting caused by the rosette disease.

PLANT SYMPTOMS

The first external indication of the rosette disease consists in a retarding of the early spring development of the fall tillers. At this time, no external lesions are consistently associated with the living tissues of the diseased plants (Plate 1, B). Lesions produced by *Helminthosporium sativum* P. K. & B. are sometimes present on the subcrown

internode[a]. Old lesions also occur in the spring on the sheaths of the old, dead, outer leaves. However, as pointed out later, these lesions are slight and they do not occur on a high percentage of the rosette-diseased plants at this time.

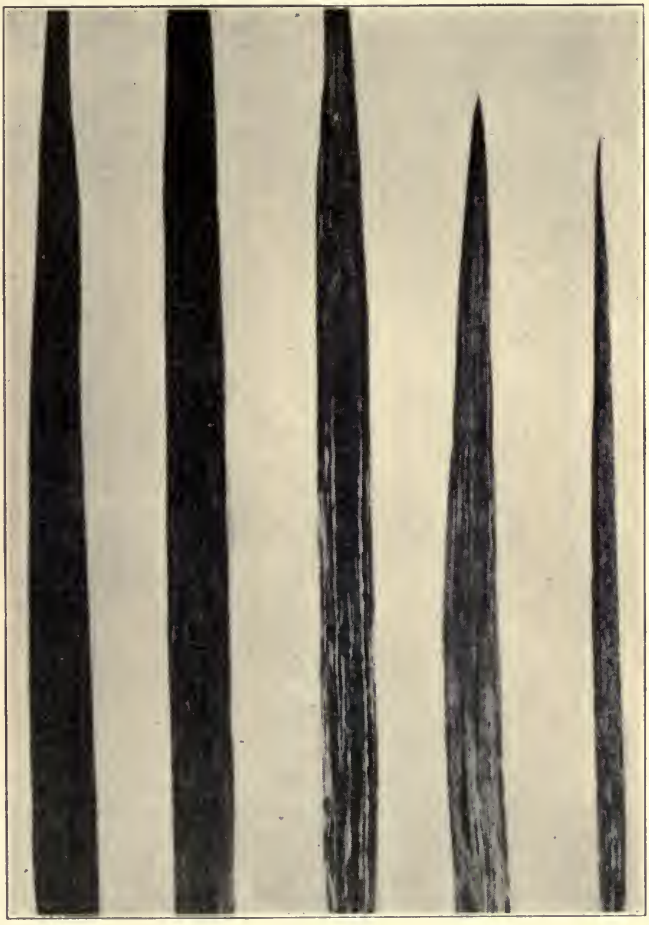

FIG. 3.—DIFFERENT DEGREES OF MOSAIC MOTTLING AS IT OCCURS ON THE CURRELL VARIETY OF WINTER WHEAT; HEALTHY LEAF ON THE LEFT

This mottling occurs on all varieties of wheat known to be susceptible to rosette and on a large number of winter varieties which do not develop rosette symptoms.

[a]The term "subcrown internode" is used to denote the structure in the wheat seedling between the crown and the base of the coleoptile. Under certain conditions this structure becomes elongated.

In a week or ten days after the first appearance of the rosette disease, the leaf blades of affected plants tend to develop a dark, rather bluish-green color. Close examination shows that this bluish-green coloration is confined largely to the leaves which were produced in the fall. As new leaves begin to develop, it will be noted that they show a very decided mottling (Fig. 3) which is typical of the mosaic diseases occurring on the grasses.[1] At the same time the diseased plants produce numerous secondary tiller buds and new tillers develop.

When these spring tillers have emerged, the basal tissues of the fall tillers begin to manifest a dull white to straw color, and in the course of another week or ten days this tissue may start to turn brown and the whole base of the plant may become rotted (Plate 1, C).

The amount of this basal rotting seems to vary considerably in different localities and under different seasonal conditions. In the vicinity of Granite City, Illinois, this rotting is more prevalent than it is near Valparaiso, Indiana. At Madison, Wisconsin, the rotting is delayed in the experimental plots when the spring is cool.

Microscopic examinations of the bases of the stunted tillers of plants manifesting the early symptoms of rosette have never shown consistently the presence of a fungus or any other known parasite. However, it has been found that these tissues contain yellowish-brown, necrotic areas located within the parenchymatous region. These necrotic areas seem to resemble those found in the stems of corn plants and sugar cane plants affected by mosaic. A rather large percentage of the host cells in the tissues of rosetted plants always show characteristic cell inclusions (Fig. 4) which were described in a previous paper.[10] These inclusions are also found in winter wheat varieties which develop the mosaic mottling, but which do not develop rosette. They have never been found in wheat plants growing in soil known to be free from the disease infestation. This subject is discussed later.

The root systems of plants in the early stages of the rosette disease do not consistently show any external signs of infection or any other injury. In a few cases, lesions have been found on the roots, but fully as many have been found on the roots of plants not showing the rosette symptoms. As the disease progresses, the root systems of affected plants show a retarded development and they become infected to some extent by various organisms. In dry situations diseased plants do not tend to send up secondary spring tillers. Such plants usually die early, forming a drooping tuft of brown, dead leaves and tillers. When heavy spring rains occur, diseased plants may be washed entirely out of the soil, leaving the ground bare between healthy plants. In situations of favorable moisture and high fertility, diseased plants often recover. Altho the fall tillers of such plants gradually die, the spring tillers may develop into short culms and produce heads. Such heads are usually small and imperfectly filled.

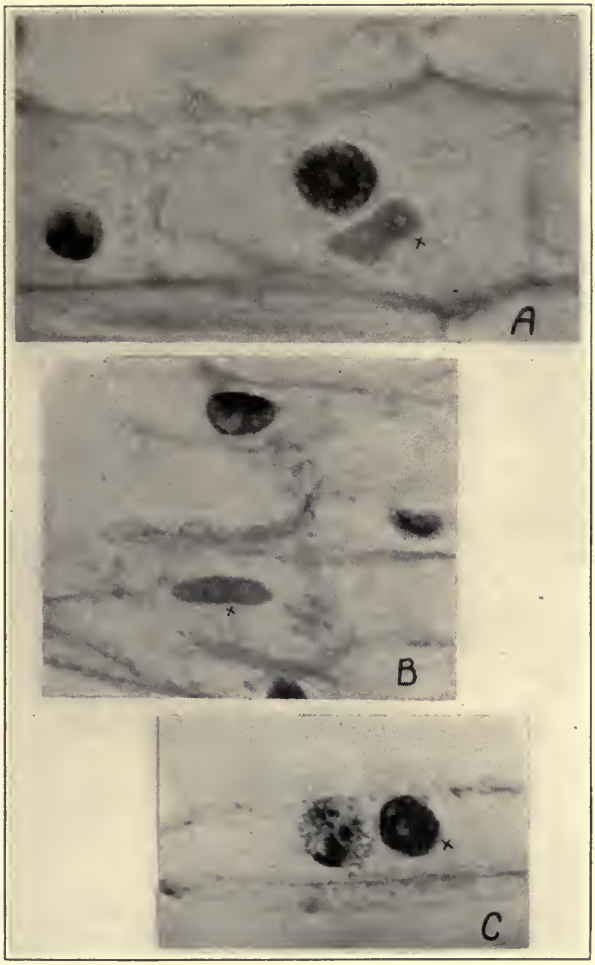

FIG. 4.—PHOTOMICROGRAPHS SHOWING DIFFERENT TYPES OF CELL INCLUSIONS IN ROSETTE-DISEASED HARVEST QUEEN WHEAT; THE CELL INCLUSIONS ARE MARKED X

A—An irregular-shaped body showing pseudopodia-like projections. It is very common to find the vacuoles surrounded by a dense ring as is here shown.

B—An elongated type of cell inclusion.

C—A very common type of inclusion found in wheat tissue from plants affected by rosette or mosiac leaf mottling. This body resembles certain of the Negri and Guarnieri bodies associated respectively with rabies and smallpox.

The most constant external symptoms of the rosette disease consist of (1) the arrested spring development; (2) the excessive tillering, producing a rosette appearance; (3) the dark blue-green coloration of the fall leaves during the spring growing period; and (4) the mosaic mottling which occurs on the leaves. On the basis of our present knowledge, the presence of Helminthosporium lesions or a rotting of the basal parts of wheat plants cannot by themselves be considered diagnostic characteristics of the rosette disease.

As pointed out above, the field spotting produced by wheat rosette occurs earlier in the spring than that produced by the take-all disease, and furthermore, the plant symptoms of these maladies are now known to be distinctly different. Plants affected by the take-all disease turn yellow and die very soon after discoloration begins. These plants show a brown to black coloration on the tiller bases and roots. This blackening or brown coloration may be due to a staining of the tissue by the fungus or to a definite crust of mycelium known as a "mycelial plate." Plants affected by the take-all disease seldom send up secondary tillers or endeavor to recover after infection. The take-all disease frequently causes nearly mature wheat plants to bleach, producing a condition commonly known as "white-heads." This condition is never produced by the rosette disease.

Hessian fly injury sometimes resembles certain stages of the rosette disease (Plate 1, D and E). In both cases, the infested plants are stunted and some of the leaves show a dark, blue-green coloration. However, the excessive tillering and the leaf mottling associated with the rosette disease are not associated with plants infested with "fly." The only time when Hessian fly infestation is apt to be confused with rosette is late spring, and then little difficulty is likely to arise, since plants infested with fly only will show the fly pupae or larvae and no leaf mottling. Those plants which show both infestations usually will show some signs of mottling.

In certain particulars the early stages of the rosette disease resemble the early stages of the nematode disease of wheat as described by Leukel.[4] In each disease there may be retarded development of the plants in the spring and the leaves may develop a dark green coloration and become very broad and thick; but in nematode-infested plants there is, in addition, usually a marked crinkling of the leaves and stems, a condition not associated with the rosette disease. Also, the leaf and stem tissues of nematode infested plants are very succulent in nature, and show a characteristic sparkling surface. None of these characters is associated with the rosette disease.

In reviewing the literature dealing with certain of the more obscure tropical diseases of the cultivated grass crops, it was found that several of these possess certain characteristics strikingly similar to the rosette disease of wheat. Excessive tillering and dwarfing are associated with

PLANTS OF WINTER WHEAT SHOWING THE EFFECTS OF ATTACKS OF THE ROSETTE AND THE HESSIAN FLY, RESPECTIVELY, COMPARED WITH HEALTHY PLANTS.

A, Healthy plant in the spring; *B* and *C*, plants of the same age as *A*, showing early and advanced stages, respectively, of the rosette; *D*, healthy plant as it appears in the late autumn; *E*, plant of the same age as *D*, infested by the Hessian fly. Note the similarities in color but the differences in the extent of tillering in plants affected by the two maladies compared with the corresponding healthy plants. (From Bul. 1137, U. S. Dept. Agriculture.)

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the Fiji, Sereh, and mosaic diseases of sugar cane.[5] The leaf mottling symptom associated with rosette is strikingly similar to the mottling associated with the mosaic disease of corn, cane, and other grasses.[1]

CAUSE OF THE DISEASE

Altho a number of theories have been advanced concerning the cause of the rosette disease, the exact cause is still undetermined. The fact that the disease does not readily develop in wheat grown under artificial conditions makes it difficult to conduct many of the experiments necessary to demonstrate the causal nature of the malady.

Previous Studies

When the disease was first discovered, many farmers thought that it was caused directly by abnormal winter conditions. The disease was also thought to be due to unfavorable soil type or unbalanced nutrition. However, subsequent observations have shown that the disease occurs with equal severity year after year on the same soil regardless of the severity of the winter. As shown previously,[6] rosette occurs on many different types of soils and under many different topographical conditions. It has also been found[6] that the disease is not essentially reduced or increased in severity when various fertilizers and soil correctives are applied to the infested soil. On the other hand, the disease[6] is prevented when the infested soil is disinfected with steam or with an .8-percent solution of formaldehyde.

These observations and results show that the causal agent is soil borne and indicate that the disease is of an infectious nature. When these studies were started, several investigators thought that the disease was caused by a severe infestation of Hessian fly. Careful observations did show some of the plants to be infested with the pupae of this insect, but by far the largest percentage of them were free from such infestation. Detailed studies on this phase of the problem conducted cooperatively by the Bureaus of Plant Industry and Entomology, U. S. Department of Agriculture,[9] show that Hessian fly is not the cause of the rosette disease. In fact these studies indicate that the disease is not caused directly by any insect.

Studies on *Helminthosporium sativum*

Several fungi have been found associated with the rosette disease, but none of them has been found to occur on all rosetted plants in the early spring when the first symptoms of the disease appear. *Helminthosporium sativum* has been found more prevalent than other fungi on the diseased plants.

In order to determine the possible relationship between *H. sativum* and the rosette disease, many observations and experiments have been conducted. It was pointed out in a previous paper[6] that certain inter-

esting correlations had been observed between the occurrence of *H. sativum* and the amount of rosette disease in experimental plots at Granite City, Illinois. However, a continuation of these and other observations at Granite City and elsewhere has not revealed a constant correlation between this parasite and the disease in question. Data have already been published[7] which show that *H. sativum* causes a mild infection on winter wheat plants in the autumn, but the percentage of infected plants is much less than the percentage of rosette-diseased plants which develop in the same plots the following spring. This relationship is rather significant when it is considered that the fall Helminthosporium infection is seldom severe enough to penetrate deeper than the first two or three leaf sheaths, and it seldom causes any vital injury to the leaves. Furthermore, it has been shown by one of the present writers[7] that the Helminthosporium disease does not develop to any extent at very low temperatures and it has been found that the rosette disease occurs in the spring before the Helminthosporium fungus renews its activity.

In order to obtain further evidence on this relationship, inoculation experiments have been carried out to determine if pure cultures of *Helminthosporium sativum* will cause the rosette disease. Numerous experiments have been conducted in the greenhouse and it has been found, as others have also found, that *H. sativum* is parasitic on wheat. However, the rosette disease has never been produced in these experiments. It was found rather early in these investigations that the rosette disease occurs only in wheat plants which have passed thru a complete or shortened winter period; hence it was useless to carry on infection experiments out of season or under ordinary greenhouse conditions.

Early in the summer of 1921, small plots of rosette infested soil near Granite City, Illinois, were sterilized with formaldehyde. Later in the summer, some of these plots were inoculated with pure cultures of *Helminthosporium sativum* isolated from wheat plants affected by the rosette disease, and the remaining plots were left uninoculated. In the autumn these inoculated and uninoculated sterilized plots were seeded with Harvest Queen wheat. The following spring, examinations showed that for some reason the disinfection had not been quite complete and therefore it was not possible to obtain trustworthy data. However, it was very evident that the introduction of *H. sativum* into the soil had not increased the amount of rosette.

During the summer of 1922, the Helminthosporium inoculation work was started at Madison, Wisconsin, in order to eliminate the possibility of accidental rosette contamination which often occurs in the rosette-infested district near Granite City. An elaborate set of experiments was carried out, but owing to the severe winter of 1923 heavy winterkilling occurred in all of the plots. However, a few wheat plants escaped winterkilling in all of the plots and no rosette developed among

plants in the soil which had been inoculated with *H. sativum*. Rosette did occur among the few surviving plants which were in the rosette infested soil which had been shipped from Illinois.

In the summer of 1923, the inoculation experiments were repeated at Madison, Wisconsin, and precautions were taken to prevent winter injury by means of a hay mulch. As a result, very little winter injury occurred in any of the plots and dependable data were obtained on the relationship between *Helminthosporium sativum* and the rosette disease. These experiments are described and the results given as follows:

Methods Employed in Studies

These studies were conducted out-of-doors in plots 30 inches wide and 36 inches long. Each plot was surrounded by a frame constructed of pine boards 8 inches wide. This frame was set 3 inches into the soil; thus 5 inches of the frame served as a protective wall surrounding the plots. Openings were cut at the bottom of each frame to provide for surface drainage. The soil used in these plots consisted of sandy loam field soil obtained from the Experiment Station farm at Madison, Wisconsin. This soil was not infested with the rosette causal agent, but in order to safeguard against accidental contamination the soil was sterilized with steam.

Two strains of *Helminthosporium sativum* were used in these studies. One, designated No. 408, was obtained thru the kindness of Dr. F. L. Stevens. This strain was isolated by Dr. Stevens from a rosette-diseased plant grown in a rosette-infested field near Granite City, Illinois, and is the one which he[12] designates Helminthosporium No. 1. The other strain, designated No. 407, was isolated by one of the writers (Webb) from a rosette-diseased plant showing the late stages of rotting.

The plots were inoculated by applying water suspensions of the conidia to the upper four inches of the soil some time before sowing the seed and again at the time of sowing as indicated in Table 2. One plot was devoted to each strain of the organism. One plot of sterilized soil was left uninoculated to serve as a control and one plot was devoted to rosette-infested soil from Granite City to serve also as a control.

In order to obtain results from soil in which *Helminthosporium sativum* had become thoroly established, one of the plots inoculated the previous year (1922) with strain No. 407 and another plot consisting of infested Minnesota soil were also included in the experiment. The Minnesota soil was very kindly supplied by Mr. J. J. Christensen of the Minnesota Agricultural Experiment Station. This soil was inoculated a number of years previous to 1923 with a pure culture of *H. sativum* isolated from diseased spring wheat grown in Minnesota. Mr. Christensen[2] previously reported that he had obtained a rosette-like manifestation in spring wheat grown in this artificially inoculated soil; consequently it was important that this soil should be included in the series.

TABLE 2.—DATA OBTAINED FROM EXPERIMENTAL PLOTS INOCULATED WITH *Helminthosporium sativum* AND FROM THE ACCOMPANYING CONTROL PLOTS

Experiments conducted at Madison, Wisconsin, during season of 1923–24. Harvest Queen winter wheat was sown in all the plots. The plots were 30 inches wide and 36 inches long and were surrounded by a frame made of pine lumber.

Plot No.	Nature of plot	Dates of seeding	Helminthosporium infection				Percentage rosette and leaf mottling	
			December 6		April 15			
			No. of plants observed	Percentage infection[e]	No. of plants observed	Percentage infection	April 15	May 10
1	Control: steam-sterilized soil	Sept. 25	25	0	122	0.9	0	0
2[a]	Control: rosette-infested soil	Sept. 25	..	..	278	2.5	0	98
3[b]	Inoculated with *H. sativum*, cult. 407	Sept. 25	25	12	234	13.2	0	0
4[c]	Inoculated with *H. sativum*, cult. 407	Sept. 25	25	50	226	18.2	0	0
5[d]	Inoculated with *H. sativum*, cult. 408	Sept. 25	25	55	133	69.2	0	0
6	Control: steam-sterilized soil	Sept. 25	25	0	122	0.9	0	0
7	Control: rosette-infested soil	Oct. 8	..	..	..	..	0	46
8	Minnesota soil infested with *H. sativum*	Oct. 8	17	35	..	..	0	0

[a]This plot contained a 4-inch layer of rosette-infested soil obtained near Granite City, Ill. In addition to the Harvest Queen, one row was devoted to the Currell variety of wheat, which is very susceptible to the mosaic mottling but not to rosette.

[b]Plot 3 was inoculated with culture No. 407 in the summer of 1922.

[c]Plot 4 was inoculated with culture No. 407 in the fall of 1923. On September 10, the top 4 inches of soil in this plot was inoculated with 1500 cc. of water containing 65,600 spores per cc. On September 25, at the time of sowing the seed, the seed trenches were inoculated with 250 cc. of water containing 66,000 spores per cc.

[d]Plot 5 was inoculated with culture No. 408, which was supplied by Dr. F. L. Stevens and which he designates Helminthosporium No. 1. On September 10, 1923, the top 4 inches of soil in this plot was inoculated with 1500 cc. of water containing 95,600 spores per cc. On September 25, at the time of sowing the seed, the seed trenches were inoculated with 250 cc. of water containing 78,000 spores per cc.

[e]The Helminthosporium lesions were extremely small during the fall and the various plots yielded quite variable results, ranging from 0 to 55 percent infection. The coleoptiles were the only parts of the plants to show lesions in the fall, and since these disintegrate rather rapidly, it was extremely difficult to take the data recorded on December 6.

Harvest Queen wheat seed was sown in each of the inoculated plots and the controls. The same lot of seed was used for all of the plots except those containing the Minnesota soil and the accompanying control. This last lot of seed was somewhat lower in susceptibility to rosette than the first lot; however, its susceptibility was sufficiently high to serve as an accurate test for the infectiousness of the experimental soil. In addition to Harvest Queen seed, one row of the Currell variety of winter wheat was sown in the control plot containing the rosette-infested soil. This variety does not develop the rosette condition, but it does develop a severe type of leaf mottling when grown in rosette-infested soil.

Results

The results of the infection studies with *Helminthosporium sativum* are given in Table 2. In all cases where early spring (April 15) observations were made, it was found that Helminthosporium infection was much more prevalent on plants growing in the plots which had been inoculated with pure cultures of *H. sativum* than it was on plants growing in the rosette-infested soil. It is especially significant that such a high percentage of infection took place in plants growing in Plot 5, which was inoculated with culture No. 408. This Plot and Plot 4 were purposely inoculated very heavily in order that *H. sativum* might be given the maximum opportunity to produce the rosette disease. However, this fungus failed to produce rosette or the mosaic leaf mottling.

A high percentage of rosette and mosaic leaf mottling (98 percent) developed in the early sown rosette-infested control (Plot 2) and 46 percent rosette and leaf mottling occurred in the late sown rosette-infested control (Plot 7) which accompanied the Minnesota soil. All of the plants grown in the Helminthosporium-infested soil, obtained from Minnesota, were exceedingly robust and there was no sign of rosette or leaf mottling on any of the plants. The reduced amount of rosette in the above rosette-infested control is assigned to the lower susceptibility of the seed used and to the fact that the seed was not sown until very late in the fall. It has been shown previously[6] that late sowing tends to reduce the amount of rosette.

The photographic evidence obtained from these experiments is shown in Figs. 5, 6, 7, and 8. It is of interest to note that the rosette-infested soil used in Plot 2 had been stored in a warm greenhouse at Madison, Wisconsin, for three years previous to using it in this experiment. During this three-year period the soil was under air-dry conditions and in spite of this the percentage of rosette and leaf mottling was not reduced.

Altho the results of the inoculation experiments are of a negative nature, it seems rather evident that they warrant consideration at this

FIG. 5.—CONTROL PLOTS 1 AND 2 USED IN THE INOCULATION EXPERIMENTS WITH *Helminthosporium sativum* TO DETERMINE WHETHER THIS FUNGUS CAUSES THE ROSETTE DISEASE IN HARVEST QUEEN WHEAT

Plot 1, control consisting of steam-sterilized soil obtained from the farm of the Wisconsin Agricultural Experiment Station at Madison, Wisconsin. No rosette developed in this plot.

Plot 2, control consisting of rosette-infested soil obtained in 1920 from a field near Granite City, Illinois. Typical rosette and mosaic leaf mottling occurred in 98 percent of the Harvest Queen plants in the five rows on the left. From 95 to 98 percent of the Currell plants in the row on the extreme right developed typical leaf mottling, but no rosette occurred in this variety. These results are in accord with all previous experiments.

During the three-year interval between the collecting of this soil and the starting of this experiment, the soil remained in an air-dry condition in a warm greenhouse at Madison, Wisconsin. No loss of virulence of the causal agent under study occurred.

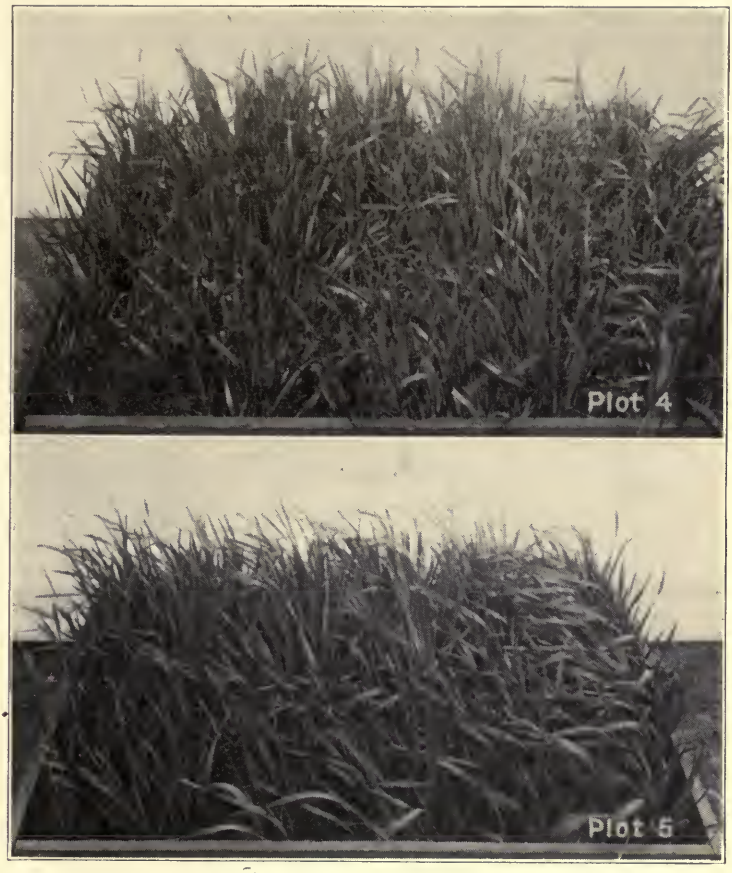

FIG. 6.—INOCULATED PLOTS 4 AND 5 WHICH ACCOMPANIED THE CONTROLS SHOWN IN FIG. 5

These plots contained the same sort of soil as Plot 1, sterilized in the same manner. They were adjacent to the controls and subjected to the same conditions. Plot 3 (not photographed) contained the same strain of the fungus as Plot 4 and presented the same appearance.

Plot 4 was heavily inoculated with *Helminthosporium sativum* (culture No. 407) isolated from a rosetted wheat plant in the late stages of the disease. No rosette or mosaic leaf mottling occurred, and in spite of the Helminthosporium infection present, no marked injury is noted.

Plot 5 was heavily inoculated with *Helminthosporium sativum* (culture No. 408), supplied by Dr. F. L. Stevens and isolated from a wheat plant in the late stages of the rosette disease. No rosette or mosaic leaf mottling occurred, and the plants showed no ill effects from the Helminthosporium infection.

The plants in Plots 4 and 5 developed in exactly the same manner as in control Plot 1. A good crop of grain was produced in all three plots.

time. Certainly if *Helminthosporium sativum* were the direct cause of the rosette disease it could have been demonstrated in some of the experiments cited. Stevens[11, 12] considers that this parasite causes rosette (called foot rot by him); however, as pointed out previously[6] it is not clear that Dr. Stevens obtained the characteristic symptoms of the rosette disease in his inoculation experiments. He did obtain the typical infection produced by *H. sativum* on seedlings, but this type of

FIG. 7.—REPRESENTATIVE PLANTS OF HARVEST QUEEN TAKEN FROM THE PLOTS ILLUSTRATED IN FIGS. 5 AND 6

A—Plant from Plot 5 inoculated with culture No. 408.
B—Plant from Plot 4 inoculated with culture No. 407.
C—Plant from Plot 1 containing sterilized soil control.
D—Rosetted plant from Plot 2 containing rosette-infested soil.

injury should not be confused with the rosette disease which attracted the attention of plant pathologists in 1919.

It has been reported[2] that *Helminthosporium sativum* produces dwarfing, proliferations, and dark green foliage on certain varieties of spring wheat and barley; however, all data available at present indicate that these conditions occur very irregularly in spring wheat and barley and that they are not identical from the standpoint of cause with the similar conditions associated with the rosette disease.

In view of the above evidence, we feel there is justification for considering that the rosette disease of winter wheat is due to some other cause than *Helminthosporium sativum.* All of the evidence which has been obtained indicates that wheat rosette is an infectious disease, and at the present time there is considerable indication that the disease may

be caused by a virus. All of the external symptoms of rosette are commonly associated with the mosaics of corn and sugar cane, and the microscopic symptoms are also similar to those associated with certain of the mosaic diseases. The mosaic mottling occurs on a large number of varieties of winter wheat and it would not be surprising to find a few

FIG. 8.—TYPICAL HARVEST QUEEN WHEAT PLANTS FROM STERILIZED AND FROM INFESTED SOIL

A—From a plot containing steam sterilized soil.

B—From a plot containing soil obtained from the Minnesota Agricultural Experiment Station, which contained *Helminthosporium sativum*. No rosette or mosaic mottling developed in this plot and the progress of the plants was the same as that of plants grown in the sterilized control plot.

C—Rosette-diseased plant from rosette-infested soil. Forty-six percent of the plants in this plot developed rosette. This percentage would have been higher if the seed had been sown earlier in the fall. Also, the particular strain of Harvest Queen used in this plot and in the accompanying plots is slightly less susceptible to rosette than that used in Plots 1 to 5.

varieties which become stunted and proliferate freely as is the case with certain varieties of sugar cane and corn when infected with the mosaic virus. Owing to the unusual conditions necessary for the development of rosette and the mosaic mottling, it has not been possible to demonstrate the virus nature of these troubles by the usual methods employed in the study of the mosaic diseases. It is hoped that studies now under way may throw some additional light on this phase of the problem.

CELL INCLUSIONS

Cell inclusions have been described in a previous publication[10] and they are illustrated here in Fig. 4. Similar inclusion bodies are also associated with several of the mosaic diseases. As pointed out by one of the present writers in a report,[8] there has been considerable controversy regarding the exact nature of many of the cell inclusions associated with virus diseases. Many investigators have held that they are definite parasitic organisms, while others hold that they are reaction products and have nothing to do with the cause of the disease. Altho the exact nature of the cell inclusions occurring in wheat is not known, it has been found that these inclusions have considerable diagnostic value.

SPREAD OF THE DISEASE

As stated previously in this paper and in an early publication,[6] the rosette-disease causal agent is in the soil and is spread by the movement of the soil. Experiments have been conducted to determine whether the malady is carried in the seed or in the stubble, but negative results were always obtained.

CONTROL MEASURES

The rosette disease of wheat has been controlled, in the areas where it has been found, by the use of varieties that are either immune from, or highly resistant to, the disease.

More than two hundred varieties and selections of winter wheat from all parts of the United States have been grown on rosette-infested soil in Illinois and Indiana during the past five years and the data obtained from the experiments appear in the literature.[6, 14] Certain of these published results, however, are sufficiently important to be included here. The susceptible varieties, arranged according to classes, are presented in Table 3, which is reproduced from a previous[14] publication. The Cereal Investigations (C. I.) accession number, or other source of seed and head descriptions are given for each variety. The percentage of plants infected in each variety was determined on the basis of macroscopic symptoms of the disease.

Harvest Queen (known as white chaffed Red Cross and Salzer's Prizetaker) is the only widely grown variety that has proved highly

susceptible. The varieties "Brunswick," Nigger, Penquite (Velvet Chaff), Missouri Bluestem, Selection from Indiana Swamp, Fultz (selection by Kentucky Agricultural Experiment Station), Miller's Pride, and Illini Chief are very susceptible. These highly susceptible varieties represent about 4 percent of the total number of varieties tested and this relatively small percentage is striking.

Twelve varieties, aggregating 6 percent of the series, proved slightly susceptible and an equal number of varieties showed slight traces of the disease.

Inconsistent results have been obtained with a few of the varieties at different places and during different years, but, for the most part, results have been very uniform. The varieties and selections resistant to the rosette disease have been listed in previous publications.[3, 14]

The more important, hard, red, winter-wheat varieties for central and northern Illinois conditions in this list are Beloglina, Black Hull, Kanred, Malakof, Michikoff, P 1066, P 1068, and Turkey Red. Among the more prominent soft, red winter wheats that are resistant to rosette are Early Harvest, Eversole, Fulcaster, Gladden, Mammoth Red, Mediterranean, Michigan Amber, Red Rock, and Red Wave.

Red Wave, which appears among the resistant or immune varieties, has largely been substituted for the Harvest Queen variety, while Fultz, many strains of which are either immune or highly resistant, has been used to some extent. A number of hard, red, winter wheats of the Turkey type, such as Illinois 10-110 and Kanred, are immune and some of these have been sown. The large number of varieties which are not susceptible to rosette makes the practical control of this disease relatively simple, but the presence of flag smut in southern Illinois in the same area with rosette presents complications. Several varieties are either immune or resistant to flag smut, as shown by Tisdale, Dungan, and Leighty.[13] The varieties resistant to flag smut are fewer in number than those resistant to rosette and the varieties which are resistant to both diseases are still fewer in number.

Of the many varieties that have been grown in both the flag smut and rosette experimental plots, those that are immune from rosette, and either immune from, or highly resistant to, flag smut are Early Harvest, Eversole, Grandprize, Illinois 10-110, Kanred, Mammoth Red, P 1066, P 1068, Red Rock, and Shepherd.

The Red Wave and Fultz varieties, while resistant to rosette, are somewhat susceptible to flag smut, and Illinois 10-110 and Kanred, while practically resistant to both diseases, are not well adapted to the southern Illinois areas. Shepherd, however, is a variety that seems to offer excellent possibilities. It is resistant to both the rosette and flag smut diseases and has yielded well in variety tests on Experimental plots in southern Illinois. A resistant selection of Harvest Queen (the so-called Salzer's Prizetaker) has been developed, and while this selec-

TABLE 3.—VARIETAL RESISTANCE IN WHEAT TO ROSETTE DISEASE

Varieties of winter wheat found susceptible to the rosette disease, in experiments conducted in the crop year 1921-22, at Granite City, Illinois, and at Wanatah, Indiana, grouped according to classes, with head characters for each and percentage of infection.

Variety	C. I. No. or source	Head characters[a]	Percentage of plants infected[b]	
			Granite City, Ill.	Wanatah, Ind.
Hard Red Winter				
Pesterboden Budapest	5789	BWG	trace	trace
Turkey Malakof	4898	BWG	0	trace
Soft Red Winter				
Alabama (Wis. No. 81)	5785	AWG	0	trace
Brown Bearded	3118	BRG	0	2
"Brunswick"[c]	Ind. Sta		—	98
China Pennsylvania Bluestem	5342	ARG	0	1
Currell	3326	ARG	0	trace
Fulcaster Stoner (Marvelous)	3605	BWG	0	trace
Fultz	5308	AWG	—	2
Fultz	3598	AWG	0	1
Fultz	1923	AWG	0	trace
Fultz (Kentucky Selection)	6896	AWG	80–90	45
Gipsy Niagara	5307	BWG	1–2	0
Harvest Queen (Control)	Granite City, Ill.	AWG	95–100	55
Harvest Queen	4882	AWG	95–100	50
Harvest Queen	Kans. Sta	AWG	95-100	—
Harvest Queen Kessinger	Ind. Sta.[d]	AWG	—	5
Illini Chief	5956	ARG	5–10	25
Illini Chief	Ind. Sta	ARG	—	1+
Jones Fife	Ind. Sta. (R. 25)	AWV	—	3
Jones Fife	Ind. Sta. (R. 13)	AWV	—	1+
Leap	5618	AWG	0	trace
Mediterranean	3332	BRG	0	trace
Mediterranean	3467	BRG	0	trace
Mediterranean Miller's Pride	4865	BRG	75	20
Missouri Bluestem	1912	BRG	95–100	75
Nigger	5366[e]	BWG	95–100	90
Penquite (Velvet Chaff)	3068	BRV	95–100	75
Poole	5653	ARG	0	1
Red May Enterprise	3399	ARG	0	trace
Red Cross	5318	ARG	0	1–2
Sel. from Ind. Swamp.	4834	BRG	95–100	40
Sel. from Ind. Swamp.	3334	BRG	1	trace
Selection No. 13631	4081	AWG (Club)	1–2	2
Selection No. 131156	4808	BRG	0	trace
Common White				
Honor	6161	ARG	0	trace

See bottom of next page for explanatory notes.

tion is susceptible to flag smut, efforts are being made to develop a strain from it which will prove resistant to both diseases.

Altho only about 10 percent of the winter-wheat varieties and selections grown on rosette-infested soil have shown definite symptoms of the disease, that is, distinct stunting and excessive proliferation, fully 85 percent of the varieties, which have heretofore been considered resistant to the rosette disease, have shown a mosaic leaf mottling in various degrees of severity. All varieties which are susceptible to rosette are also susceptible to the leaf mottling. In general, the mottling does not seem to interfere with the development of the plants; however, in a few cases (Malakof, Crimean, and Currell) the mottling is severe and it appears to affect the normal development of the plants. It is of interest to note that certain varieties show a variation in the distribution and severity of the rosette symptoms for different years and it is of further interest to note that certain varieties frequently show gradations between typically rosetted and healthy plants.

Other possible control measures have been investigated, and, while they have proved effective, they are not practical from the field standpoint. Sterilization of infested soil with either steam or formaldehyde adequately controls the disease. Moreover, the fall date of planting in infested soil bears a definite relation to the disease. Within limits, the distribution and severity of the disease decreases directly with delayed planting. No symptoms have been noted with Harvest Queen (the most susceptible variety) when it was planted so late in the fall that it did not emerge until spring, or on any of the spring varieties.

CONCLUSIONS

The cause of wheat rosette is still unknown. There are indications that it may be a phase of a mosaic disease.

The causal agent is soil borne and the disease recurs every year when susceptible varieties of winter wheat are sown on infested soil. The disease has not been noted in spring wheat.

Since the disease occurs in relatively few varieties it can be successfully controlled by sowing those which are resistant. The mosaic leaf mottling which occurs on rosetted plants and also independently of rosette occurs on a large number of varieties when sown in infested soil. However, this leaf mottling does not seem to cause a reduction in crop yield in most varieties.

Notes to Table 3:

[a] A = awnless; B = bearded; W = white chaffed; R = red chaffed; G = glabrous, or smooth chaffed; V = velvet chaffed.

[b] Trace = less than .5 percent; 0 = no disease; — = not tested at that place.

[c] Received by the Indiana Agricultural Experiment Station from Brunswick, Germany.

[d] Either a somewhat resistant strain or mixed somewhat with some similar resistant variety.

[e] A strain descended from a single plant selection. Other varieties of the Fulcaster group to which this strain is similar are generally immune.

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